

Method for determining the envelope curve of a modulated signal

The invention relates to a method for determining the envelope curve of a modulated signal, for example for determination of the values for a CCDF diagram.

The determination of the envelope curve of a modulated signal is required in particular for determination of the CCDF (Complementary Cumulative Distribution Function) but also for other applications. The CCDF diagram indicates the probability that the signal level of the envelope curve of the analysed signal exceeds a specific level value. From the course of the CCDF diagram, the parameter of the crest factor *inter alia* can be determined, which parameter indicates the ratio of the power occurring at the maximum in the signal relative to the average power. The crest factor assists the operator of a modulated high frequency transmitter to determine the optimal modulation of the transmitter amplifiers. On the one hand, the transmitted power is intended to be as high as possible in order that the signal-to-noise ratio at the receivers is as large as possible. On the other hand, the transmitting power must not be too large in order to avoid destruction due to short power peaks in the transmission amplifiers. If the measured CCDF course together with the course of an ideal signal is represented, conclusions can be made with respect to non-linearity and limitation effects in the transmitted signal.

A measurement value detecting device and display device for a CCDF diagram is known from DE 199 10 902 A1. There also, a step of signal processing resides in determining the envelope curve of the modulated signal or the power of the envelope curve. In column 10, line 47 to column 11, line 28, it is proposed for determining the envelope curve power to sample the signal with the quadruple symbol frequency, to square the digital values of a group comprising four samples, to summate and then to divide by 4. Hence, a sliding average value of the power values of the instantaneous amplitude of the modulated signal is

produced, which corresponds to a low-pass filtering. It is however disadvantageous in this mode of operation that the thereby necessary squaring of the sampled digital values leads to higher-frequency spectral components. The subsequent non-ideal low-pass filtering leads to imprecisions in the CCDF measurement. More precisely, the squaring of the samples leads to higher-frequency spectral components which are no longer removed correctly by means of averaging (= filtering with a filter with $\sin(x)/x$ frequency response).

The object therefore underlying the invention is to indicate a method for determining the envelope curve of a modulated signal which operates with relatively high precision.

The object is achieved by the features of claim 1.

In contrast to the known method, determination of the envelope curve is effected according to the invention not by low-pass filtering but instead the digital samples are Fourier-transformed in the frequency range. In the frequency range, the range of positive frequencies or the range of negative frequencies is then removed. Then a Fourier inverse transform in the time domain follows. Only then are the values of the inverse-transformed samples formed. It is also shown later in this application that the absolute value of the inverse-transformed samples represents the envelope curve of the modulated high frequency signal.

In contrast to the value formation and subsequent low-pass filtering, the method according to the invention has the advantage that implementation of the method is independent of the quality of the low-pass filtering, is independent of the type of signal and of its spectral position, and in addition independent of the synchronisation state of the high frequency signal to be measured. The method according to the invention is in addition substantially more precise than the known method with low-pass filtering.

The sub-claims relate to advantageous developments of the invention.

It is advantageous, in addition to the range of negative or positive frequencies, also to remove the level component at the DC frequency 0 after the Fourier transform in the frequency range. It is ensured as a result that the direct voltage offset of a non-ideal analogue/digital converter has no influence on the method according to the invention. The ideal signal has no direct voltage component in the intermediate frequency plane so that removal of the direct voltage component does not falsify the measurement result.

Furthermore, it is sensible to further process the samples, which are inverse-transformed in the time domain, only in such a limited range that the cyclic continuation of the signal, which is caused by the Fourier transform and inverse Fourier transform, is suppressed.

Claims 6, 7, 8 and 9 relate to a corresponding digital storage medium, computer programme or computer programme product based on the method according to the invention.

The invention is described in more detail subsequently with reference to the drawing. There are shown in the drawing:

Fig. 1 an example of a CCDF diagram;

Fig. 2 a block diagram of the method according to the invention;

Fig. 3 a diagram to explain the mode of operation of the method according to the invention;

Fig. 4 the samples which are Fourier-transformed in the frequency range and

Fig. 5 the samples which are inverse-transformed in the time domain.

The method according to the invention is explained subsequently for the application example for determining the instantaneous power of the envelope curve for a CCDF diagram. As already explained, the method according to the invention is however not restricted to this application and is suitable for all applications in which the instantaneous level of the envelope curve or signal values derived from the latter, such as e.g. the power, i.e. the square of the level, are required.

Fig. 2 demonstrates the method according to the invention by means of a block diagram. The high-frequency input signal S , which is modulated by a modulation signal, is firstly sampled digitally on a sampling and holding circuit 1. Digital samples A_n of the input signal S are thereby produced. The samples A_n are then subjected to a Fourier transform for example with an algorithm of the fast Fourier transform (FFT, Fast Fourier Transform). The Fourier-transformed samples B_n are produced as a result. The Fourier transform is illustrated in Fig. 2 by block 2.

Due to the Fourier transform of a sampled real signal, Fourier-transformed samples are produced as is known, which samples extend both over the range of negative frequencies and over the range of positive frequencies. According to the invention, either the range of negative frequencies or the range of positive frequencies is removed from the Fourier-transformed samples B_n . If the index n is running, which indexes the Fourier-transformed samples B_n , for example from $-2^N/2$ to $2^N/2-1$, N being a whole natural number, then the range of negative frequencies corresponds to the samples B_n with $n < 0$ or the range of positive frequencies corresponds to the samples B_n with $n > 0$.

The remaining samples, which are either only positive or only negative, are designated in Fig. 2 with B'_n . Trimming of the samples in the negative

frequency range is illustrated in Fig. 2 by the block 3 which has a transfer function $H(f)$ which is different from 0 only in the range of positive frequencies. These sideband-cleaned, Fourier-transformed samples B'_n are subsequently transformed back in the time domain by an inverse Fourier transform. Likewise, a fast digital Fourier inverse transform (IFFT, Inverse Fast Fourier Transform) can be used, which is illustrated in Fig. 2 by block 4. In the time domain, the inverse-transformed samples C_n are present, the value of which is still to be formed finally in the value former 5. The value of the samples, which are inverse-transformed in the time domain, is designated in Fig. 2 with D_m .

In the case of application of the CCDF diagram, there must now be established in a block 6 the relative frequency with which the square of the value-samples D_m^2 , which corresponds to the power, exceeds a threshold value x in relation to the average power D_{eff}^2 on a logarithmic scale which is scaled in dB. Expediently, the squaring is implemented not before but after logarithmising, i.e. instead of a multiplication by the factor 10, a multiplication by the scaling factor 20 is effected:

$$10 \cdot \log \frac{D_m^2}{D_{eff}^2} = 10 \cdot \log \left(\frac{D_m}{D_{eff}} \right)^2 = 20 \cdot \log \frac{D_m}{D_{eff}} \quad (1)$$

The CCDF diagram can then be displayed on a display device 7, for example a screen.

As Fig. 5 shows, the signal, which is initially Fourier-transformed and then inverse-transformed in the time domain, said signal comprising the digital samples C_n , is cyclic due to the final time and frequency sampling, i.e. in the example illustrated in Fig. 5, the signal has a cycle length $m_2 - m_1 - 1$. The index n runs in Fig. 5 from 0 to $2^N - 1$. It is therefore expedient to further process the inverse-transformed samples C_n only in a limited range 13 so that the cyclic continuation is suppressed, i.e. there applies

$C_m = C_n$ with $m_1 \leq m \leq m_2$. The amount value is calculated only from this limited section C_m of the inverse-transformed samples, which corresponds to the description in Fig. 2. The value formation is then effected according to the formula

$$D_m = |C_m| = \sqrt{\operatorname{Re}\{C_m\}^2 + \operatorname{Im}\{C_m\}^2} \quad (2)$$

The steps for determining the values of the inverse-transformed samples D_m are repeated until a sufficient number of values D_m is available such that the effective value D_{eff} of the value sequence can be determined therefrom according to known rules. The power of this effective value is then the reference value for the indication of the level on the horizontal axis of the CCDF diagram (0 dB). On the vertical axis of the CCDF diagram, the CCDF value, which belongs to the respective power level, is plotted, i.e. that relative frequency with which the power value x relative to the average power D_{eff}^2 is exceeded. This is effected by means of the formula

$$CCDF(x) = p \left(20 \cdot \log_{10} \frac{D}{D_{\text{eff}}} \geq x \right) \quad [x] = \text{dB} \quad (3)$$

with

p: probability of occurrence or relative frequency

D: instantaneous value of the envelope curve

D_{eff} : effective value of the envelope curve

Instead, as here, of comparing level dimensions or voltage dimensions, of course also the corresponding power dimensions (instantaneous power D^2 and average power D_{eff}^2) are related directly to each other. Then the pre-factor of the logarithm does however change from 20 to 10.

The function of the method according to the invention is described in more detail with reference to Figs. 3 and 4. The signal S can be factorised in a Fourier sequence, i.e. any arbitrary input signal can be constructed from a series of cosine signals with different signal levels and phases. In the following, only one of these Fourier components is considered, which can be written in general as follows:

$$s_1(t) = A(t) \cdot \cos(\omega \cdot t + \varphi) \quad (4)$$

The envelope curve to be determined here would therefore be $A(t)$. The transmission signal concerns a real signal which can be represented complexly as follows:

$$\begin{aligned} s_1(t) &= A(t) \cdot \left[\frac{1}{2} \cdot (e^{j(\omega t + \varphi)} + e^{-j(\omega t + \varphi)}) \right] \\ &= \frac{A(t)}{2} \cdot e^{j(\omega t + \varphi)} + \frac{A(t)}{2} \cdot e^{-j(\omega t + \varphi)} \end{aligned} \quad (5)$$

This relation can be presented graphically by means of a vector diagram, as illustrated in Fig. 3.

The signal $s_1(t)$ comprises a first rotating vector 8, which rotates to the left with the angle frequency ω , and a second rotating vector 9 synchronised thereto which rotates to the right with the same circular frequency ω . The omission of the range of negative frequencies according to the invention leads to the fact that the rotating vector 9 is suppressed. In reverse, omission of the range of positive frequencies, which is just as possible as an alternative, leads to the fact that the rotating vector 8 is suppressed. Filtering in the frequency range leads therefore to omission of one of the two terms in equation (5). If for example the component with the negative frequency, i.e. the rotating vector 9 which rotates to the left in Fig. 3, is

omitted in equation (4), then the following result is produced after the amount formation:

$$s_2(t) = \left| \frac{A(t)}{2} \cdot e^{+j(\omega t + \varphi)} \right| = \left| \frac{A(t)}{2} \cdot e^{-j(\omega t + \varphi)} \right| = \frac{|A(t)|}{2} \quad (6)$$

The value corresponds according to Fig. 3 to the length of the remaining vector. When using the signal $s_2(t)$ for determining the CCDF diagram, the fact that $s_2(t)$ can only be positive because of the value formation, is of no importance. In the case of the CCDF diagram, powers are compared with each other which can only be positive. The division by the factor 2 does not likewise influence the result of the CCDF diagram.

The knowledge obtained above by means of a Fourier component can of course be applied readily to the total signal which represents a linear superposition of a multiplicity of Fourier components. For this purpose, the Fourier-transformed samples B_n are represented in Fig. 4. The index n runs here from $-2^N/2$ to $2^N/2-1$. It is detectable that the range of negative frequencies 10, in the case of a real input signal S , is the mirror image of the range 11 with positive frequencies.

If either the range 10 of negative frequencies is omitted in the further signal processing, i.e.

$$B'_n = 0 \text{ for } n < 0 \text{ and}$$

$$B'_n = B_n \text{ for } n > 0$$

or if the region 11 of positive frequencies is omitted, i.e.

$$B'_n = B'_n \text{ for } n < 0 \text{ and}$$

$$B'_n = 0 \text{ for } n > 0,$$

then the envelope curve is automatically produced after inverse transformation in the time domain after formation of the absolute value, as was illustrated previously with reference to Fig. 3.

Expediently, not only either the range 10 of negative frequencies or the range 11 of positive frequencies is suppressed, but in addition also the level component 12 for the zero frequency; in the indexation used here, i.e. B_0 with $n = 0$. Thus a possibly present direct voltage component (DC-offset) is suppressed. Since the evaluated signals stem from the intermediate frequency plane, these should actually contain no direct voltage component. If however a direct voltage component is present, then this stems for example from a direct voltage offset of the analogue-digital converter and removal of this direct voltage component increases the measurement precision.

An example of a CCDF diagram, the underlying envelope curve of which was obtained with the method according to the invention, is illustrated in Fig. 1. As already mentioned, the relative frequency p is plotted for this purpose in a CCDF diagram such that a specific level D on a logarithmic scale is exceeded. In the example illustrated in Fig. 3 of an input signal which has been modulated digitally according to the 8VSB standard, exceeding the effective power with 3 dB occurs still with a relative frequency of approximately 10%, whilst exceeding the effective power with more than 6 dB occurs already with a relative frequency significantly smaller than 1%.

As already mentioned many times, the method according to the invention is not restricted to the application case for determining instantaneous level values or instantaneous power values for a CCDF diagram, but in general is suitable for determining the envelope curve of a modulated signal. The method can be implemented both with digital hardware, for example by using FPGA (Free Programmable Gate Array), or with software in a special processor, ideally in a digital signal processor (DSP).